XII.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XXIII. — MEASUREMENT OF THE STRENGTH OF TELEPHONE CURRENTS.

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So far as is known to the authors of the present paper, no measurements have ever been made of the strength of such telephone currents as are actually used in the transmission of speech. The few figures that have been given are estimates rather than measurements. Some very interesting results are given by Dr. C. J. Blake (Jour. Soc. Tel. Engineers, 1878, p. 247) regarding the logographic values of the different vowels as determined by the throw of the needle of a mirror galvanometer used in connection with a magneto transmitter. This logographic effect, however, should be carefully distinguished from that of the alternating currents utilized in the continuous transmission of sound, as, even with apparatus suitable for the measurement of such currents, it is liable to mask the phenomena to be studied unless care be taken to avoid such disturbing effects.

The lack of figures in so interesting and important a subject as the one under consideration arises from the fact that an electro-dynamometer of some form must be used for the necessary measurements, and an exceedingly sensitive instrument is essential in order to obtain sufficient deflection to give results of any value.

A form of electrical balance similar to that figured by Maxwell (Electricity and Magnetism, 2d ed., Vol. II. p. 342) was at first constructed, but this failed to give satisfactory results. Subsequently, success was obtained by using a Kohlrausch unifilar electro-dynamometer, made by Hartmann, of the form described in Wiedemann's Annalen, Vol. XV., 1882, p. 550. The instrument was modified by removing the heavy movable coil furnished by the maker, which was of altogether too low resistance for our purpose, and replacing it by a

lighter and closely wound coil of No. 36 (B. & S.) copper wire, with a suspending wire of the same gauge and 40 centimeters in length. The resistance of the instrument was 206 ohms, that of the suspended coil being 166 ohms. In some of the experiments the metallic vane, which in the instrument as described by Kohlrausch dips into a vessel of dilute sulphuric acid, was removed, and a needle point dipping into mercury substituted, the connection with the telephone being made through this. But the greater freedom from disturbances when the vane was used made it preferable. The rapid alternation of currents prevented any difficulty from polarization, as was shown by the fact that with a source of sound of constant intensity the same results were obtained whether dilute sulphuric acid or mercury was employed. A reading telescope and scale graduated to millimeters served to determine the deflections of the dynamometer coil, the telescope being at a distance of 1.5 meters from the mirror.

The dynamometer was usually placed in the secondary circuit of a small induction coil, the resistance of which was about 800 ohms. The microphone transmitters were placed in the primary circuit, with two Grenet cells arranged in parallel circuit. When the magneto transmitter was used it was placed directly in circuit with the electro-dynamometer.

The dynamometer was so placed that, when no current was flowing, the axis of its suspended coil was at right angles to the magnetic meridian. No special care was taken to secure this accurately, as the action of the deviating couple due to the earth's magnetism was found to be quite negligible in comparison with variations caused by unavoidable differences in the intensity of the sounds acting upon the transmitter. Deflections of the suspended coil were read by the use of a mirror, telescope, and scale, as the ordinary method of bringing the scale-reading back to zero by moving the torsion head of the instrument could not be used, since it was impossible with the voice to sustain a note for a sufficient length of time. The deflections were therefore read by the observer, and the strength of the current subsequently determined from these by the following method. A Daniell cell was placed in circuit with the dynamometer, using a mercury contact to avoid the polarization which would ensue with dilute sulphuric acid, and by means of a rheostat interposed in the circuit the resistance was varied until deflections were obtained corresponding with those given by the telephone currents. The electromotive force of the cell divided by the total resistance in the circuit gave the current corresponding to any given deflection. A galvanometer was also

inserted in the circuit; but as there was some uncertainty about its constant and law of deflection which we were prevented from determining by want of time, the method already stated was relied upon, merely using the figures given by the galvanometer as a check upon the results. The current strength as given in this paper is therefore the strength of the steady current which gives the same dynamometer reading as the alternating currents of the telephone. No correction for the self-induction of the dynamometer was attempted, as the range of variation in the readings shows that at the present stage of our research no real increase in accuracy would be secured by doing this.

The absence of any means of obtaining a definite and constant intensity of the voice renders it very difficult to obtain uniformity in results. Care was taken, however, not to continue the experiment very long at any one time, as the voice of the singer or speaker became wearied, and was less under control.

In telephonic experiments care must be taken, as already intimated, to avoid the logographic disturbance that arises from the strong air pressure developed on beginning the utterance of different sounds, as the magnitude of the temporary deviation produced by this often far exceeds the permanent deflection which is given by the continuous telephone current. This can be done by raising the voice very gradually; but a better method, which we have employed, is to interpose a key, which keeps the circuit open until the sound is fully developed. Then, on closing the circuit, the deflection quickly becomes steady, and the disturbance in question is avoided.

Measurements were made with the Hunning, Fitch, Blake, Edison, and Bell magneto transmitters. The Hunning transmitter uses carbon in a granulated form, and the Fitch employs two hard carbon disks as electrodes. The structure of the other transmitters is too well known to require any description.

The vowels *a*, *o*, *u*, *i* (German sounds) were spoken or sung into the transmitter successively, all at the same pitch, viz. the B of 480 vibrations, and with the same intensity as nearly as this could be realized. The deflections obtained are given below in full, in order to furnish some idea of the degree of uniformity obtained. Several separate series are given for each transmitter. In some cases the loudness of the voice varied somewhat in passing from one series to the next.

The readings are given in centimeters and tenths.

Hunning Transmitter.

	a.	*o.*	*u.*	*i.*
(1.)	8.0	17.5	7.0	1.7
	7.5	12.2	7.0	1.3
	7.3	15.2	8.0	1.8
	9.2	12.3	8.4	1.8
	7.4	12.5	7.9	1.9
(2.)	11.5	15.5	9.8	4.0
	15.0	30.0	10.0	3.7
	15.0	20.5	11.0	3.5
	14.0	17.0	10.0	3.5
	12.5	18.5	11.0	3.0
(3.)	10.0	12.5	6.5	1.5
	10.0	11.5	7.5	2.0
	13.0	15.0	8.0	2.5
	11.5	12.5	5.0	2.5
	10.1	12.4	7.0	2.2
(4.)	12.5	13.0	8.0	2.0
	10.5	15.0	7.2	3.0
	12.5	15.0	9.0	2.5
	12.5	16.0	8.9	3.5
	12.0	16.0	8.7	3.5

Fitch Transmitter.

	a.	*o.*	*u.*	*i.*
(1.)	7.5	9.5	7.5	4.0
	5.5	9.0	7.0	4.0
	6.5	9.0	4.2	1.7
	5.0	6.5	7.0	4.5
	5.5	6.7	6.4	4.2
(2.)	6.2	8.0	5.7	1.8
	6.5	7.4	5.5	0.8
	5.0	7.4	5.4	3.8
	5.4	7.7	5.4	2.7
	6.4	7.0	6.0	2.0

	a.	*o.*	*u.*	*i.*
(3.)	6.0	7.4	6.1	2.1
	6.2	9.0	6.0	3.0
	6.4	8.2	5.5	2.7
	5.4	8.0	5.5	2.4
	5.7	8.0	6.2	3.2

Blake Transmitter.

	a.	*o.*	*u.*	*i.*
(1.)	0.5	0.3	0.2	0.0
	0.4	0.7	1.3	0.1
	0.4	0.8	0.4	0.0
	0.3	0.7	0.4	0.0
	0.4	0.7	0.3	0.0
(2.)	0.3	0.7	0.3	
	0.6	0.7	0.4	
	0.6	1.2	0.3	
	0.4	1.0	0.5	
	0.5	0.8	0.5	
(3.)	0.5	0.8	0.4	
	0.6	0.8	0.3	
	0.5	0.9	0.3	
	0.5	0.6	0.6	
	0.7	0.8	0.7	

Edison Transmitter.

	a.	*o.*	*u.*	*i.*
(1.)	0.3	0.4	0.8	0.2
	0.3	0.5	1.1	0.1
	0.3	0.7	0.8	0.1
	0.2	0.7	0.7	0.1
	0.3	0.5	0.7	0.3
(2.)	0.3	0.5	0.7	0.1
	0.2	0.7	0.8	0.1
	0.2	0.7	0.8	0.2
	0.2	0.6	0.4	0.1
	0.4	0.7	0.3	0.2

	a.	*o.*	*u.*	*i.*
(3.)	0.4	0.9	0.5	0.1
	0.2	0.7	0.5	0.1
	0.2	0.8	1.1	0.2
	0.3	0.7	1.2	0.2
	0.4	0.8	0.8	0.3

MAGNETO TRANSMITTER.

	a.	*o.*	*u.*	*i.*
(1.)	0.4	1.2	0.8	0.1
	0.3	1.3	2.3	0.3
	0.6	4.0	3.6	0.3
	0.4	2.9	5.4	0.5
	0.3	2.0	3.4	0.2
(2.)	0.7	1.0	2.1	0.2
	0.4	1.2	2.0	0.3
	0.6	1.3	2.0	0.7
	0.6	2.2	3.2	0.7
	0.8	2.7	2.7	0.5
(3.)	0.6	3.1	2.2	0.4
	0.6	2.7	2.3	0.3
	0.5	2.2	1.9	0.3
	0.6	2.3	2.4	0.5
	0.7	2.5	2.2	0.2

Some experiments were also made upon a Dolbear electrostatic receiver in circuit with a Hunning transmitter and high resistance induction coil. The currents produced when speech was readily transmitted and reproduced by the Dolbear receiver were too slight to be measured by the dynamometer, although amply sufficient to reproduce speech in a magneto receiver interposed in the circuit.

At first sight some of the results given in the preceding tables are quite unexpected. Thus in some cases the magneto transmitter gives a current as great as the Blake carbon transmitter, or even greater, although as used in actual practice the latter is far louder. This probably comes from the fact that with the magneto transmitter the lips were habitually placed close to the mouthpiece of the instrument, so that, even if the same actual strength of voice were used, the effect on the diaphragm of the magneto would be greater than on the diaphragm of

the Blake transmitter. It was impossible to use the same loudness of voice with the lips close to the mouthpiece of the latter transmitter, as the scratching sound which always appears with a microphone too strongly excited became very marked. Therefore, while keeping the voice at the same intensity, we removed the mouth farther from the transmitter, until the scratching ceased. In fact, the difference in the size and shape of the mouthpieces of the different instruments and the position of the mouth in speaking, whether pressed against the mouthpiece or at a little distance from it, always affect both the absolute and relative strength of the vibrations of the diaphragm with different vowels, and hence of the resulting currents. A further interesting illustration of this will be seen by comparing the results with the Hunning and Edison transmitters.

In another series of experiments the sound of a C_4 stopped organ-pipe giving 512 vibrations per second was substituted for the voice. Very great constancy in its intensity was secured by blowing it with a blast and using a very large bottle as a pressure regulator. Three tubes were inserted through the cork of the bottle. Through one of these the air from the blast entered the bottle; through a second it passed to the organ pipe; while the third tube was drawn to a small aperture at its extremity, which allowed a greater or less quantity of air to pass out, according as the pressure from the blast tended to increase or diminish. Observations were made at intervals for ten minutes. Only slight oscillations of the coil occurred during this time. The following are the mean readings with different transmitters: —

Hunning	7.9
Fitch	3.4
Blake	0.7
Edison	0.2
Magneto	0.5

The strength of the current in ampères in the different experiments was as follows.

VOWEL SOUNDS.

Hunning Transmitter (from Series 3).

Vowel.	Mean Deflection.	Current.
a	10.9	0.000737
o	12.8	0.000787
u	6.8	0.000503
i	2.1	0.000213

Fitch Transmitter (from Series 3).

Vowel.	Mean Deflection.	Current.
a	5.9	0.000450
o	8.1	0.000548
u	5.8	0.000442
i	2.7	0.000264

Blake Transmitter (from Series 3).

a	0.6	0.000123
o	0.8	0.000144
u	0.5	0.000114
i	—	—

Edison Transmitter (from Series 1).

a	0.3	0.000088
o	0.6	0.000123
u	0.8	0.000144
i	0.2	0.000072

Magneto Transmitter (from Series 2).

a	0.6	0.000123
o	2.6	0.000260
u	2.2	0.000238
i	0.4	0.000103

SOUND OF C_4 ORGAN-PIPE.

Transmitter.	Current.
Hunning	0.000550
Fitch	0.000361
Blake	0.000132
Edison	0.000072
Magneto	0.000114

In the case of some of the very small deflections observed, the current was calculated on the assumption that the deflection varied as the square of the strength of the current.

A few preliminary experiments were made, using a method by which we hope to obtain further results. A Thomson quadrant electrometer was used with the telephone on the same plan as that originally suggested by Joubert for its use with dynamo machines giving

alternating currents. The needle and one pair of the quadrants were connected with one terminal of the telephone, and the other pair of quadrants with the remaining terminal. There was not sufficient time at our disposal to obtain any series of measurements by this method, but results were reached which give encouragement as to its availability. It is possible that this method may prove especially useful in the study of electrostatic telephones.

The results given in the preceding pages are to be regarded only as preliminary to a more extended series of measurements. But while they are yet necessarily somewhat meagre, they at least show, first, that an electro-dynamometer of a simple construction is sufficient, not merely to detect, but also to measure telephone currents; and, secondly, that the strength of these currents, especially when good carbon microphone transmitters are used, is far in excess of what has hitherto been supposed.

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